Available online at www.sciencedirect.com
ScienceDirect

Agricultural Sciences in China
2008, 7(1): 32-40
January 2008

Variation Laws of Anthocyanin Content in Roots and Their Relationships with Major Economic Traits in Purple-Fleshed Sweetpotato [*Ipomoea batatas* (L.) Lam]

FU Yu-fan[1], CHEN Min[2], YE Xiao-li[1], ZHANG Qi-tang[1], LIAO Zhi-hua[1], YANG Chun-xian[1] and HE Ping[1,3]

[1] *Key Laboratory of Eco-Environments in Three Gorges Reservoir Region, Ministry of Education/School of Life Science, Southwest University/Chongqing Sweetpotato Research Center, Chongqing 400715, P.R.China*
[2] *School of Pharmacy, Southwest University, Chongqing 400715, P.R.China*
[3] *Chongqing Municipal Forestry Bureau, Chongqing 400715, P.R.China*

Abstract

Variation laws of anthocyanin content in root during the development and among the varieties, and their relationships with major economic traits in purple-fleshed sweetpotato [*Ipomoea batatas* (L.) Lam] were studied in the present article. The dynamics of 20 economic traits in 13 purple-fleshed sweetpotato varieties at 20, 40, 60, 80, 100, 120, and 140 d after their transplanting were investigated, and these traits included anthocyanin content in root, length of the longest vine, number of base branches, root number, dry matter contents in stem, foliage and root, fresh/dry weight of root, fresh/dry weight of stem, fresh/dry weight of foliage, fresh/dry weight of stem and foliage, fresh/dry weight of whole plant, and rations of photosynthate to root, stem, and foliage. The correlations between the variations of anthocyanin content and the other 19 economic traits among varieties and during the whole developing stages, and the correlations of daily increase of anthocyanin content with other 10 kinds of yields were analyzed. The results showed that: (1) During the whole development, the anthocyanin content had three variation types, i.e. a slow-increase type, a fluctuating-change type, and a devious-rising type, and had different responses to the growth of length of the longest vine, number of base branches, fresh/dry yield of root, and photosynthate allotments. (2) The anthocyanin contents among 13 varieties began to have significant difference after 20 d, and showed completed differentiation during 40-100 d, which had significantly negative correlationships with the number of base branches, fresh/dry yield of root, photosynthate allotment ratio to root, and had significant positive correlationships with dry matter content of root, length of the longest vine, fresh/dry yield of stem, dry yield of whole plant and photosynthate allotment ratio to foliage. (3) Because of the significantly negative correlation between daily increase of anthocyanin content and dry matter weight of root, the anthocyanin accumulation competed with dry matter accumulation for photosynthate in root, and the competitive relation was resolved in different ways in different purple-fleshed sweetpotato (PFSP) varieties. So, there had three variation types of anthocyanin content among PFSP varieties during their development, and had different correlations between these variations of anthocyanin content and the major economic traits.

Key words: purple-fleshed sweetpotato, anthocyanin, anthocyanin accumulation, economic trait, correlationship

INTRODUCTION

Sweetpotato [*Ipomoea batatas* (L.) Lam] is an important crop used for food, feed, industrial material (Lu *et al.* 1998; Huang *et al.* 2003), and a burgeoning energy resource in China (Mays *et al.* 1990; Yu *et al.* 1996). Purple-fleshed sweetpotato (PFSP) has large quantities

---

This paper is translated from its Chinese version in *Scientia Agricultura Sinica*.

FU Yu-fan, Ph D candidate, Mobile: 13638388306, E-mail: xsfanyufu@126.com; Correspondence HE Ping, Professor, Mobile: 13908388745, E-mail: heping@swu.edu.cn of anthocyanin synthesis in its root (Kehr *et al.* 1955; Imbert *et al.* 1966; Odake *et al.* 1992; Terahara *et al.* 1999). Anthocyanin in PFSP was formed through cyanidin or peonidin first glycosylation by sophorose and glucose, and farther acylation by caffeic acid, ferulic acid, and *p*-hydroxy benzoic acid (Terahara *et al.* 1999; Suda *et al.* 2003). It had been reported that anthocyanin in PFSP had good stability (Bassa and Francis 1987; Lu and Li 2001; Ye *et al.* 2003), and more importantly, had many physiologically hygienic functions (Cho *et al.* 2003; Suda *et al.* 2003; Philpott *et al.* 2004; Sakatani *et al.* 2004; Fu *et al.* 2005; Wang *et al.* 2005, 2006). So it had expansive prospects in food, cosmetic, and medicine (Suda *et al.* 2003; Fu *et al.* 2005). The previous studies had by and large concentrated on the extraction and purification of anthocyanin, physical and chemical properties of anthocyanin, and the physiologically hygienic functions, and had made good progresses (Suda *et al.* 2003; Xie *et al.* 2004; Yang *et al.* 2004; Fu *et al.* 2005; Gao and Xu 2005). The content and composition of anthocyanin were directly relative to the physiologically hygienic functions, exploiture and usage of PFSP (Yoshimoto *et al.* 1999; Yoshinaga *et al.* 1999, 2000; Philpott *et al.* 2003; Fu *et al.* 2005) were an important material basis and assessment criteria of PFSP qualities, and were also important subjects of PFSP breeding, research, and exploiture. But there were fewer reports about variations of anthocyanin content among varieties and during development (Yoshinaga *et al.* 1999, 2000; Zhao *et al.* 2006), and no report about relationships of these variation with major economic traits in PFSP. Variation of anthocyanin content and their relationships with major economic traits among 13 PFSP varieties during 20-140 d after transplanting were reported in this article to provide a scientific base for further research, breeding, cultivation, and exploiture of PFSP.

MATERIALS AND METHODS

Materials

Thirteen PFSP varieties involved in this study were as follows: No. 1 Rizishu 4, No. 2 Rizishu 5, No. 3 Rizishu 7, No. 4 Rizishu 8, No. 5 Rizishu 9, No. 6 Rizishu 13, No. 7 Yamagawamurasaki, No. 8 Ningzhishu 1, No. 9 Guangzishu 1, No. 10 Yuzi 263, No. 11 J36-4, No. 12 I19-7, and No. 13 I19-43.

Field design and investigation

Thirteen materials were grown in the experimental field at Beibei District Institute of Agriculture Science, Chongqing, China, and transplanted on June 7, 2005. These materials were randomly arranged into plots with length 4.2 m, width 2.4 m. Each plot had three ridges and was cultivated with 60 plants, amounting to 60 000 plants ha^{-1}. The environmental factors, such as, light, soil fertility, and field management were under the same control.

The root samples were collected at 20, 40, 60, 80, 100, 120, and 140 d after transplanting, respectively. Two adjacent plants were regarded as a repeat, and three repeats were collected for each variety (the plants near the borders were not investigated because of the edge effect). The major economic traits, such as, length of the longest vine, number of base branches, fresh weight of stem, fresh weight of foliage, root number, and fresh weight of root were investigated. The stem and foliage were mixed respectively, and sampled for determining their dry matter content, and all roots of per repeat were sampled for detecting the content of dry matter and anthocyanin.

Detection of contents of dry matter and anthocyanin in root

The roots were cleaned and cut into 1 cm × 1 cm × 1 cm pieces, homogenized by mixing fully and divided into two shares; one was used to detect the dry matter content of the root, the other was used to detect the content of anthocyanin.

The preparation of PFSP dry powder and the detection of anthocyanin content were carried out according to Lu *et al.* (1997). To protect the anthocyanin from being destroyed at high temperature, root granules for powder were first baked at 40°C for 72 h, as the weight loss wasn't beyond 0.3%, and the dry matter content, d_{40}, was detected. The dry root granules were milled until they passed through a 90 mesh $inch^{-1}$ sieve, and then the PFSP dry powder was stored at low temperature and torrefaction refrigerator. The contents of anthocyanin were detected when all powder samples were prepared. PFSP powder of 1 g was dissolved in 200 mL 0.5 mol L^{-1} citric acid buffer (pH = 3) in a 60°C water bath for 2 h. The extraction was detected the absorption, *a*, at 530 nm, where *a* was the anthocyanin content in the PFSP powder. The anthocyanin content in fresh PFSP root was denoted as A, $A = a \times d_{40}$. In this article, the content of anthocyanin indicated the assorption of fresh PFSP root at 530 nm, and its unit was as same as that of absorbency.

Statistical analysis

The data were analyzed by Excel 2003 and SPSS 11.0, which included seven economic traits (i.e., anthocyanin content of each variety and each repeat in different developing stages, length of the longest vine, number of base branches, root number, dry matter contents in stem, foliage, and root), 10 yield traits (i.e., fresh/dry weight of root, fresh/dry weight of stem, fresh/dry weight of foliage, fresh/dry weight of stem and foliage, fresh/dry weight of whole plant), three traits of photosynthate allocation (i.e., the ratios of dry root, stem, and foliage to the dry whole plant), 11 daily increase traits (i.e., content of anthocyanin and 10 yield traits in different developing stages). The daily increase per trait = (Latter value - Former value)/20.

The variation types of anthocyanin content during development and their differentiation process among 13 PFSP varieties were summarized, through the analysis of one-way ANOVA and LSD (least significant diference) multiple-comparison between the differences of anthocyanin contents among 13 PFSP varieties at every stage and the dynamic changes of anthocyanin content in 13 PFSP varieties at different developing stages. The correlations of anthocyanin content in PFSP varieties and 6 other economic traits, 10 yield traits, and 3 photosynthate ration traits occurred in every variety during whole stage and among varieties at every stage were studied. Also the correlations of daily increase of anthocyanin content and daily increase of other 10 yield traits were analyzed.

RESULTS

The anthocyanin accumulation types

Variation of anthocyanin content in root during development After transplanting 20 to 60 d, the variation trend of anthocyanin content of 12 PFSP varieties was first increased and then decreased except No. 10, which was increased all the time (Figs.1-3). After 60 d, the variation of anthocyanin content had three types among these varieties. The type I included No. 1, No. 2, No. 4, and No. 5. Their anthocyanin contents were 0.435-0.575 after 140 d, with the average of 0.508. Their anthocyanin contents always increased, and daily increase of anthocyanin content was always positive during this time, though the increase velocity was slow and not stable (Fig.1, Table 1). The type II included No. 3, No. 9, No. 10, and No. 12. Their anthocyanin contents were 0.132-0.488 after 140 d, and the average was 0.375, which was similar to those after 40 or 60 d. There were some fluctuations on anthocyanin content variation trends. The fluctuant

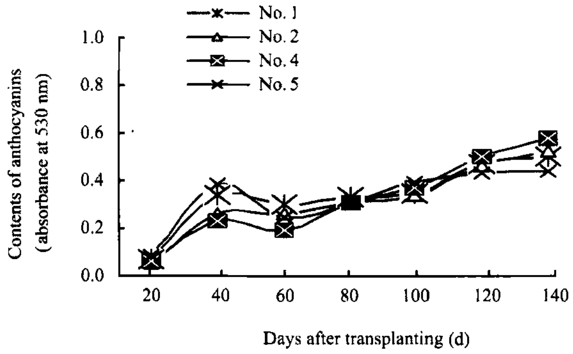

Fig. 1 Type I of anthocyanin accumulation.

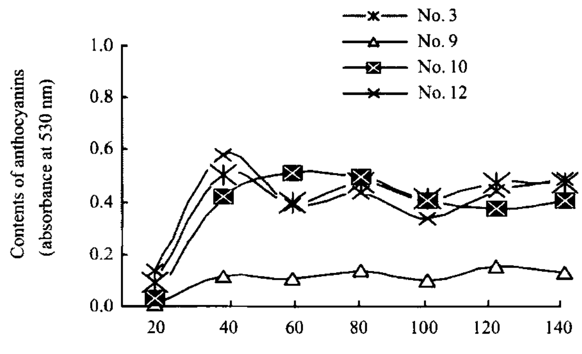

Fig. 2 Type II of anthocyanin accumulation.

curve of type II showed that the daily increases of anthocyanin content were sometimes positive and sometime negative (Fig.2, Table 1). The type III included No. 6, No. 7, No. 8, No. 11, and No. 13. Their anthocyanin contents were 0.407-0.851 after 140 d, with the average of 0.615 (Fig.3). Their anthocyanin contents were altogether higher than those of types I and II (Fig.4). There were increase and decrease trends of anthocyanin content variation during 60-140 d, which reached the maximum on day 120. The daily increases of anthocyanin content were sometimes positive and sometimes negative, and the positive daily increase of anthocyanin content was higher than those of types I and II. The anthocyanin contents of type III were devious variation during the development process, but the total variation trend was increased, and the contents after 140 d were notably higher than those after 40 d. (Fig.3, Table 1).

Therefore, the anthocyanin content in PFSP had an obvious fluctuant change, and had three obvious stages in the whole developing stage. The first stage was from 20 to 40 d after transplanting, the anthocyanin content was increased obviously, and the rate of accumulation was rapid; the second stage was from 40 to 60 d after transplanting, the anthocyanin content was decreased except in No. 10; the third stage was from 60 to 140 d after transplanting, the change of anthocyanin content was fluctuant.

The first and second stages of most varieties were similar, but different in the third stage. According to the difference in the third stage, there were three types of the anthocyanin content variation in PFSP during the development, the slow-increase type (type I), the fluctuating-change type (type II), and devious-rising type (type III). Thirteen PFSP varieties were divided

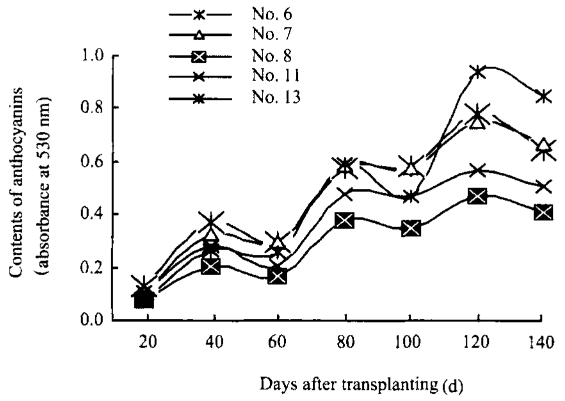

Fig. 3 Type III of anthocyanin accumulation.

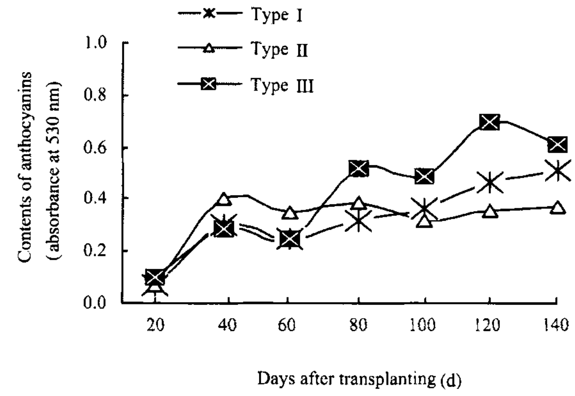

Fig. 4 Three types of anthocyanin accumulation.

Table 1 The daily increase of anthocyanin content in root of 13 PFSP varieties during different developing stages[1)]

Type of anthocyanin accumulation	Variety code[2)]	Developing stages after transplanting					
		20-40 d	40-60 d	60-80 d	80-100 d	100-120 d	120-140 d
Type I	No. 1	0.0134	-0.0019	0.0019	0.0007	0.0060	0.0014
	No. 2	0.0101	-0.0001	0.0025	0.0017	0.0061	0.0031
	No. 4	0.0085	-0.0017	0.0057	0.0029	0.0068	0.0037
	No. 5	0.0153	-0.0069	0.0028	0.0046	0.0019	0.0001
Type II	No. 3	0.0207	-0.0055	0.0040	-0.0030	0.0028	0.0001
	No. 9	0.0055	-0.0007	0.0015	-0.0017	0.0025	-0.0009
	No. 10	0.0192	0.0046	-0.0006	-0.0047	-0.0016	0.0017
	No. 12	0.0223	-0.0096	0.0024	-0.0049	0.0052	0.0024
Type III	No. 6	0.0123	-0.0040	0.0143	0.0003	0.0098	-0.0068
	No. 7	0.0109	-0.0016	0.0144	-0.0005	0.0090	-0.0043
	No. 8	0.0065	-0.0019	0.0105	-0.0016	0.0060	-0.0030
	No. 11	0.0085	-0.0037	0.0137	-0.0005	0.0048	-0.0031
	No. 13	0.094	-0.0004	0.0165	-0.0061	0.0236	-0.0044

[1)] The daily growth rate of anthocyanin content is absorbance at 530 nm 100 d^{-1}.

[2)] The codes and names of varieties: No. 1, Rizishu 4; No. 2, Rizishu 5; No. 3, Rizishu 7; No. 4, Rizishu 8; No. 5, Rizishu 9; No. 6, Rizishu 13; No. 7, Yamagawamurasaki; No. 8, Ningzishu 1; No. 9, Guangzishu 1; No. 10, Yuzi 263; No. 11, J36-4; No. 12, I19-7; No. 13, I19-43. The same as below.

into three types, I, II, and III, according to their anthocyanin content variation type. Fig.4 reflected the variation of the average of anthocyanin content of the three types PFSP varieties in the different developing stages.

Variation of anthocyanin content in root among PFSP varieties The results of one-way ANOVA and LSD multiple-comparison between the differences of anthocyanin contents among 13 PFSP varieties at every stage showed that there had no difference about anthoyanin contents among varieties at 20 d after transplanting, but had significant difference at 40, 60, 80, 100, 120, and 140 d. There still had no differentiation among the three types PFSP varieties until 40 d because of no significant difference between variation among the same sort varieties and variation among the different sort varieties in their anthocyanin content. Variation of anthocyanin content among 13 varieties exhibited varieties differentiation after 40 d, and varieties of type II first separated from 13 PFSP varieties during 40 to 80 d because their significant distinguish with types I and III in anthocyanin contents, and remainder varieties continued to be divided into types I and III during 80 to 100 d. Differentiation among the same sort varieties was also taken place, just no more than that between the different sort varieties.

The correlations between variation of anthocyanin content and major economic traits

The correlations between variation of anthocyanin content during whole development and major economic traits The results of the correlations between the variation of anthocyanin content during whole development and major economic traits indicated that the anthocyanin content variation of varieties belonging to type II had insignificant correlations with these traits, whereas, those of varieties belonging to types I and III had significant positive correlations with length of the longest vine, fresh/dry weight of root, and photosynthate allocation to root, and they also had significant negative correlations with photosynthate allocation to stem and foliage. The anthocyanin content variation of varieties belonging to type I had significant positive correlations with number of base branches; the anthocyanin content variation of varieties belonging to types I and III had no obvious correlations with other 12 economic traits, such as, number of the roots (Table 2).

The correlations between variation of anthocyanin content among varieties and major economic traits The results of the correlations between variation of anthocyanin content among varieties and major economic traits showed that the anthocyanin content had a different correlationship with other 19 major economic traits in the different developing stages, especially in the later developing stage. There were significant negative correlations of anthocyanin content and number of base branches, fresh/dry weight of root, and photosynthate allocation to root, and also had significantly positive correlations with dry matter content of root, length of the longest vine, fresh/dry weight of stem, dry weight of whole plant, and photosynthate allocation to foliage, while no obvious correlations with other traits (Table 3).

The daily increase in correlations of anthocyanin content variation and major yield traits During the developing stage of PFSP, the daily increase and change in anthocyanin content were shown in Table 1. The correlation analysis on the daily increase of anthocyanin content and 10 major yield traits showed that the daily increase of anthocyanin content had significant negative correlations with fresh/dry weight of root, and fresh/dry weight of whole plant, although, had no significant correlation with the other yield traits (Table 4). The

Table 2 The correlation coefficients between anthocyanin content and economic traits in 13 PFSP varieties during the whole stage

Economic trait	Variation type and content of anthocyanin of 13 PFSP varieties												
	Type I				Type II				Type III				
	No. 1	No. 2	No. 4	No. 5	No. 3	No. 9	No. 10	No. 12	No. 6	No. 7	No. 8	No. 11	No. 13
ET1	0.542^{*}	0.749^{**}	0.432^{*}	0.531^{*}	0.047	0.045	0.370	-0.458	0.573^{*}	0.872^{**}	0.496^{*}	0.706^{**}	0.632^{*}
ET2	0.581^{*}	0.723^{**}	0.557^{*}	0.475	-0.055	0.241	-0.468	-0.313	0.770^{**}	0.777^{**}	0.844^{**}	0.327	0.625^{*}
ET3	0.563^{*}	0.701^{**}	0.527^{*}	0.453	-0.085	0.358	-0.463	-0.321	0.740^{**}	0.764^{**}	0.846^{**}	0.332	0.596^{*}
ET4	0.706^{**}	0.732^{**}	0.776^{**}	0.348	-0.300	0.344	-0.384	-0.490	0.693^{**}	0.748^{**}	0.656^{**}	0.464	0.694^{**}
ET5	-0.740^{*}	-0.589^{*}	-0.569^{*}	-0.072^{**}	-0.087	-0.016	0.357	-0.493	-0.707^{*}	-0.444	-0.419	-0.121	-0.332

ET1, length of the longest vine; ET2, weight of fresh roots; ET3, weight of dry roots; ET4, ration trait of photosynthate allocation to root; ET5, number of base branches.
* Correlation significant at $P < 0.05$. ** Correlation significant at $P < 0.01$. The same as below.

result of further partial correlation analysis showed that the daily increase of anthocyanin content was only a significant negative correlation with the daily increase of dry matter in the root ($r = -0.237$, $P = 0.042$). Therefore, when the rates of the PFSP swelling and photosynthate accumulation in the root were rapid, the increase rate of anthocyanin content became slow, sometimes the content even decreased, whereas, when the anthocyanin content increased, the swelling rate was slow.

DISCUSSION

Yoshinaga *et al.* (2000) divided the 10 PFSP varieties into two types according to their anthocyanin content, high content type and low content type, but their anthocyanin content variation was of one type only, wherein there was a fast increasing stage after transplanting for 21-42 d, a stable fluctuant stage after 42-84 d, and a little change stage after 84-119 d. The anthocyanin content of this type, that is, after 119 d was not noticeably different from that after 40 d. Therefore, they thought the anthocyanin content of PFSP became stable after 40 d, and there was no obvious increase or decrease from then. The type Yoshinaga *et al.* (2000) found was consistent with the type II in this article, namely the fluctuating-change type. However, this study not only confirmed the existence of anthocyanin content increasing rapidly during 20-40 d after transplanting and the existence of anthocyanin accumulation fluctuating-change type II, but also found the slow-increase type and devious-rising type. The anthocyanin contents of the new two types after 140 d were noticeably higher than those after 40 d, although the new two types were different in accumulation process. These new results may be caused by the geographical source of materials, the time of developing, and the variation in eco-environment.

During the sweetpotato developing progress, there were some morphological and physiological changes, such as, the vine becoming longer, photosynthate transferring from the foliage and stem to the root, root gradually swelling, dry matter accumulation in the root, and so on. The developing dynamic biological response of root anthocyanin content to these economic traits varied in different types. The slow-increase type and devious-rising type had an obvious positive response to some economic traits, such as, the longer of the longest vine, increase in fresh/dry weight of root, rising the ratio of photosynthate allocation to root, and so on, and also had an obvious negative response to the decreasing of ratios of photosynthate allocation to stem and foliage. The difference of the slow-increase type and devious-rising type was that there were different responses to the development of the number of base branches, the former had a positive response, whereas, the latter had no response. These two types also had no obvious response to the other 12 economic traits. The anthocyanin content of varieties belonging to the fluctuant-change type had no response or laggard response to the

Table 3 The correlation coefficients of anthocyanin content and some economic traits among PFSP varieties at different developing stages

Economic trait	Anthocyanin contents at different developing stages (absorbance at 530 nm)						
	20 d	40 d	60 d	80 d	100 d	120 d	140 d
Length of the longest vine	0.029	0.059	0.460**	0.088	0.400*	0.380*	0.410*
Number of base branches	0.066	0.180	-0.250	0.041	-0.058	-0.332*	-0.307*
Weight of fresh stem	0.090	0.116	-0.278	0.299*	0.300*	0.072	0.287
Weight of dry stem	0.082	0.149	-0.267	0.270	0.411**	0.150	0.321*
Root number	-0.024	0.067	-0.118	0.071	-0.064	-0.342*	-0.351*
Weight of fresh root	-0.301	-0.451**	-0.321*	-0.118	-0.352*	-0.480**	-0.550*
Weight of dry root	-0.267	-0.418**	-0.239	0.020	-0.158	-0.440**	-0.378*
Dry matter content of root	0.297	0.543**	0.348*	0.304*	0.457**	0.274	0.425**
Dry yield of whole plant	0.098	0.152	-0.303	0.155	0.017	-0.317	0.325*
Ration trait of photosynthate allocation to root	-0.227	-0.496*	-0.190	-0.065	-0.364*	-0.460**	0.356*
Ration trait of photosynthate allocation to foliage	0.167	0.468*	0.259	0.013	0.162	0.276	-0.361*

Table 4 The correlation coefficients between daily increase rates of anthocyanin content and 10 kinds of yield traits in 13 PFSP varieties root

	Root		Stem		Foliage		Vine		Whole plant	
	FW	DW	FW	DW	FW	DW	FW	DW	FW	DW
r	-0.246*	-0.288*	-0.166	-0.233	0.129	0.110	-0.051	-0.102	-0.276*	-0.311*

FW, fresh weight; DW, dry weight; *r*, correlation coefficient.

developing dynamic of all traits during the growth and developing stages. Therefore, the anthocyanin content of varieties belonging to the slow-increase type was increasing all the time accompanied by the development of economic traits, such as, the longer of the longest vine, the increase in the number of base branches, the swelling of root, and the transferring of photosynthate from the stem and foliage to the root. The anthocyanin content in varieties belonging to the devious-rising type was deviously rising because of no response in the branches, and the anthocyanin content of varieties belonging to the fluctuant-change type had little change because of no response to any trait.

Among PFSP varieties, there were significantly negative correlations of anthocyanin content with the number of base branches, fresh/dry weight of root, and the ratio of photosynthate allocation to root. There were significantly positive correlations of dry matter content of root, length of the longest vine, fresh/dry weight of stem, dry weight of the whole plant, and the ratio of photosynthate allocation to foliage, and it had no obvious correlation with other traits. Therefore, the higher the yields in fresh/dry weight of root, dry weight of root, and the ratio of photosynthate allocation to root were, the lower the anthocyanin content was. The higher the dry matter content in the root and the longer the length of the longest vine were, the higher the anthocyanin content was. These correlations were more obvious in the late developing stage. These results could be used to explain some phenomenon, such as, low sweetpotato fresh root yield with high anthocyanin content in practice.

The study on the daily increase of anthocyanin content in PFSP having obviously negative correlation with the daily increase of dry root weight showed that there was competition among anthocyanin accumulation, root swelling, and photosynthate allocation, which could have been caused by the competition of resources between the physiological progresses of anthocyanin accumulation and root swelling, because of anthocyanin synthesizing with malonyl CoA and *p*-coumaroyl CoA as the precursor in PFSP root (Kehr *et al.* 1955; Holton and Cornish 1995). The early developing stage of PFSP, after transplanting 20 to 40 d, the rate of anthocyanin accumulation was the fastest because there was no swelling in the root, although the anthocyanin content was low, it increased all the time. During the period of 40-60 d, the root began to have a certain swelling, the anthocyanin content was diluted and decreased with increase of the cell numbers in the root (Yoshinaga *et al.* 2000). After 60 d, the contradiction of root swelling and anthocyanin accumulation had different solutions in different varieties. The rates of root swelling and anthocyanin accumulation were low in type I varieties, hence the contradiction of both was not obvious. Their anthocyanin contents increased all the time, but the total anthocyanin contents and fresh root yields were both low. The absolute values of daily increase of anthocyanin content in type II varieties were low and the anthocyanin accumulation had little effect on the root swelling, so their total anthocyanin contents were medium, but the fresh root yield was highest. The competition of the root swelling and anthocyanin accumulation in type III varieties was very obvious, thus, the root swelling in some varieties, such as, Yamagawamurasaki, J36-4 and I19-43 was slow when the daily increase of anthocyanin content was high, and sometimes it was rapid when the daily increase of anthocyanin content was slow. Generally, the anthocyanin contents in type III varieties were high, whereas, the fresh root yields and dry root yields were low, but there was a special variety of I19-43, of which both the anthocyanin content and fresh root yield were high, and whose anthocyanin content was the highest among 13 varieties, and fresh root yield was the fourth highest, and its dry matter was high, which could be the result of the contradiction between root swelling and anthocyanin accumulation being harmonized. The anthocyanin contents of type III varieties reached the highest after transplanting 120 d, there was a certain significance for PFSP production.

These studies in the present article showed that, on one hand, the negative correlations between the anthocyanin content and fresh/dry root yield among the sweetpotato varieties could be explained, and on the other hand, it was possible to breed the good quality variety with both high anthocyanin content and high fresh root yield, although usually, the high anthocyanin content would accompany the low fresh root yield.

The anthocyanin content variation characteristics would be further certified by other methods such as molecular method, and would give scientific proof for the further research, breeding, cultivation, exploiture, and utilization of PFSP.

CONCLUSION

There had three variation types of anthocyanin content among PFSP varieties, resulted from the different ways of settling the competitive relations in accumulations of anthocyanin and dry matter in the root, and from the significant difference and differentiation of anthocyanin content among PFSP varieties during their development. There had different correlations between these variations of anthocyanin content and the major economic traits.

Acknowledgements

This study was supported financially by the Natural Science Foundation of Chongqing Science and Technology Commission, China (CSTC2005BB1105), National Key Technology R&D Program of China (2006BAD01A06-2-06), and Animal and Crop Fine Variety Innovation Program of Chongqing City, China (10379).

References

Bassa I A, Francis F J. 1987. Stability of anthocyanins from sweet potatoes in a model beverage. *Journal of Food Science*, **52**, 1753-1754.

Cho J S, Kang J S, Long P H, Jing J, Back Y, Chung K S. 2003. Antioxidant and memory enhancing effects of purple sweet potato anthocyanin and cordyceps mushroom extract. *Archives of Pharmacal Research*, **26**, 821-825.

Fu Y F, Chen M, Ye X L. 2005. Progresses and counter-measure of research and utilization on purple-fleshed sweetpotato. In: Ma D F, Liu Q C, eds, *Sweetpotato Breeding and Industrialization in China*. China Agricultural University Press, Beijing. pp. 234-240. (in Chinese)

Gao Y X, Xu Z H. 2005. Research progress on purple sweetpotato color. *China Food Additives*, **1**, 1-6. (in Chinese)

Holton T A, Cornish E C. 1995. Genetics and biochemistry of anthocyanin biosynthesis. *The Plant Cell*, **7**, 1071-1083.

Huang J K, Song J, Qiao F B, Fuglie K O. 2003. *Sweetpotato in China: Economic Aspects and Utilization in Pig Production*. International Potato Center, East, Southeast Asia and Pacific Region (CIP-ESEAP), Bogor, Indonesia. pp. 19-23.

Imbert M P, Seaforth C E, Williams D B. 1966. The anthocyanin pigments of the sweetpotato *Ipomoea batatas* (L.) Lam. *Proceedings of the American Society of Horticultural Science*, **88**, 481-485.

Kehr A E, Ting Y C, Miller J C. 1955. The site of carotenoid and anthocyanin synthesis in sweet potatoes. *Proceedings of the American Society of Horticultural Science*, **65**, 396-398.

Lu G Q, Li X L, 2001. Stability of red pigments from purple sweetpotato (*Ipomea batatas* (L.) Lam) and other five natural red pigments. *Journal of Zhejiang University* (Agriculture and Life Sciences), **27**, 635-638. (in Chinese)

Lu G Q, Qiu Y J, Lou X B, 1997. Study on the technological conditions for extracting pigments from purple sweet potato. *Journal of Zhejiang Agricultural University*, **23**, 105-107. (in Chinese)

Lu S Y, Liu Q C, Li W J. 1998. *Sweetpotato Breeding*. China Agriculture Press, Beijing. pp. 1-4. (in Chinese)

Mays D A, Buchanan W, Bradford B N, Giordano P M. 1990. Fuel production potential of several agricultural crops. In: Janick J, Simon J E, eds, *Advances in New Crops*. Timber Press, Portland, USA. pp. 260-263.

Odake K, Terahara N, Saito N, Toki K, Honda T. 1992. Chemical structures of two anthocyanins from purple sweetpotato, *Ipomoea batatas*. *Phytochemistry*, **31**, 2127-2130.

Philpott M, Gould K S, Lim C, Ferguson L R. 2004. *In situ* and *in vitro* antioxidant activity of sweetpotato anthocyanins. *Journal of Agricultural and Food Chemistry*, **52**, 1511-1513.

Philpott M, Gould K S, Markham K R, Lewthwaite S L, Ferguson L R. 2003. Enhanced coloration reveals high antioxidant potential in new sweetpotato cultivars. *Journal of the Science of Food and Agriculture*, **83**, 1076-1082.

Sakatani M, Suda I, Oki T, Kobayashi S, Kobayashi S, Takahashi M. 2004. Purple sweetpotato anthocyanin reduces the intracellular hydrogen-peroxide (H_2O_2) level in bovine embryos caused by heat stress. *Sweetpotato Research Front*, **18**, 2.

Suda I, Oki T, Masuda M, Kobayashi M, Nishiba Y, Furuta S. 2003. Physiological functionality of purple-fleshed sweet potatoes containing anthocyanins and their utilization in foods. *Japan Agricultural Research Quarterly*, **37**, 167-173.

Terahara N, Shimizu T, Kato Y, Nakamura M, Maitani T, Yamaguchi M, Goda Y. 1999. Six diacylated anthocyanins from the storage roots of purple sweet potato, *Ipomoea batatas*. *Bioscience, Biotechnology, and Biochemistry*, **63**, 1420-1424.

Wang G L, Yue J, Li H Y, Fang H J. 2005. Extraction of anthocyanin from sweetpotato by macroporous resin and its bacteriostatic mechanism. *Scientia Agricultura Sinica*, **38**, 2321-2326. (in Chinese)

Wang G L, Yue J, Su D X, Fang H J. 2006. Study on the antioxidant activity of sweet potato anthocyanin and its inhibiting effect on growth of cancer S_{180}. *Acta Nutrimenta Sinica*, **28**, 71-74. (in Chinese)

Xie Y Z, Yin Q H, Qiu R L. 2004. Study and utilization of sweetpotato with high anthocyanin. *Rain Fed Crops*, **24**, 23-25. (in Chinese)

Yang Z X, Wang Y J, Gao L. 2004. The research advances of the anthocyanins pigment from purple sweet potato. *Journal of Qindao University* (Engineering and Technology Edition), **19**, 32-36. (in Chinese)

Ye X L, Li X G, Li K P, Mu H. 2003. Studies on the hue stability of anthocyanin in purple sweetpotato. *Journal of Southwest China Normal University* (Nature Science), **28**, 725-729.

Yoshimoto M, Okuno S, Yoshinaga M, Yamakawa O, Yamaguchi M, Yamada J. 1999. Antimutagenicity of sweetpotato (*Ipomoea batatas*) roots. *Bioscience, Biotechnology, and Biochemistry*, **63**, 537-541.

Yoshinaga M, Tanaka M, Nakatani M. 2000. Changes in anthocyanin content and composition of developing storage root of purple-fleshed sweet potato (*Ipomoea batatas* (L.) Lam). *Breeding Science*, **50**, 59-64.

Yoshinaga M, Yamakawa O, Nakatani M. 1999. Genotypic diversity of anthocyanin content and composition in purple-fleshed sweetpotao (*Ipomoea batatas* (L.) Lam). *Breeding Science*, **49**, 43-47.

Yu B J, Zhang F M, Zheng Y G, Wang P. 1996. Alcohol fermentation from the mash of dried sweet potato with its dregs using immobilized yeast. *Process Biochemistry*, **31**, 1-6.

Zhao D L, Tang J, Zhang Y G, Shi X M. 2006. Comparison of relative content of anthocyanins of 8 purple sweet potato germplasms. *Chinese Agricultural Science Bulletin*, **22**, 156-157. (in Chinese)

(Edited by ZHANG Juan)